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Reassessing materials for use by persons with special needs to expediently shelter in place

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INTRODUCTION

On February 10, 2003, the American public was advised by US Department of Homeland Security Secretary Tom Ridge to purchase duct tape and plastic sheeting to create safe havens in their homes. This was to be achieved by sealing off an internal room in which to shelter in the event of a terrorist attack involving biological, chemical, or radioactive weapons. This two decades-old practice of expedient sheltering relies on reducing the flow of exterior air into a "safe room" by employing readily available materials.^{1,2}

Cutting plastic sheeting into properly sized covers for windows, doors, and vents and applying duct-tape strips to attach the sheeting to adjoining walls and ceilings is not considered a difficult task for the general public. However, for those with significant physical, medical, or mental impairments, these steps may be too difficult and stressful during an emergency situation. In seeking to address this disparity in self-sheltering abilities, Argonne National Laboratory (ANL) in Illinois conducted a preliminary assessment of several alternative materials for reducing air infiltration into designated safe rooms that could be readily used by persons with special needs. Based on the criteria of effectiveness in reducing air infiltration, ease of application, and ease of removal, our research found that painter's tape and self-adhering laminate provide a level of protection that is at least equal to conventional duct tape and plastic sheeting when placed directly over the air gaps around windows and doors.

BACKGROUND

The current practice of expedient sheltering evolved from a concept of "ad hoc shelter" put forth by the North American Treaty Organization in 1983, whereby the general population was to protect itself from chemical warfare agent exposure by using plastic sheeting to seal off a predesignated room.³ This concept was modified when Israel's combat line moved from the border to the home front during the 1991 Gulf War, at which time civilians were educated by the Israeli Home Front Command on how to prepare themselves for the direct threat of warheads of unknown composition by establishing protected shelters.⁴ Although the Doctrine of the Protection of the Civilian Population in Israel requires that all new building construction as well as additions to existing buildings be equipped with an engineered sealed shelter, people in buildings without shelters are to practice "expedient sheltering." This process involves selecting an inner room, sealing joints with adhesive tape, and completing the sealing process with plastic around every window (Figure 1).⁵ In the United States, the basic tenets of sheltering in place for short-term protection, as currently prescribed by federal agencies,⁶⁻⁹ state and local governments,¹⁰⁻¹² and national organizations,^{13,14} generally involve some combination of steps, which include:

- closing and locking all doors and windows;
- turning off all fans and heating and air-conditioning systems;

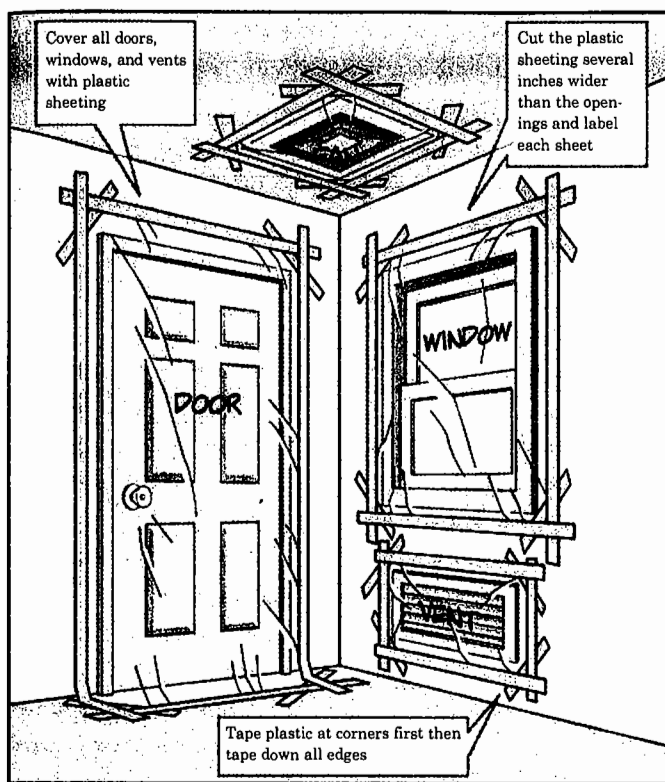


Figure 1. "Expedient sheltering" involves sealing the windows, doors, vents, registers, and electrical outlets of an interior room to provide short-term protection in the event of a chemical, biological, or radioactive emergency.

- closing fireplace dampers;
- proceeding to an interior room and using duct tape to apply plastic sheeting covers over all windows, doors, vents, and registers;
- placing wet towels (dry towels are as effective) under connecting doors; and
- turning on a radio or television and tuning to a local Emergency Alert System station for further instructions.

Since the terrorist attack on the United States in September 2001, concern by federal, state, and local governments as well as the disabled community has been growing over how to protect persons with special needs. An estimated 54 million disabled men, women, and children live in the United States,¹⁵ including those

with mental or emotional disabilities and others with physical disabilities that impact hearing, vision, and mobility. The focus on emergency preparedness for the elderly and disabled was reinforced recently in testimony before the US Senate Special Committee on Aging¹⁶ and in the Disaster Mobilization Initiative being carried out by the National Organization on Disability.¹⁷

Moreover, there are components of the Americans with Disabilities Act (ADA) (Pub. L. No. 101-336) that apply directly to government emergency planning. Among its requirements, the ADA (42 USC. Section 12132) states, "No qualified individual with a disability shall, by reason of such disability, be excluded from participation in or be denied the benefits of the services, programs, or activities of a public entity or be subjected to discrimination by any such entity." In the case of *Shirey v. City of Alexandria School Board* in Virginia (229 F.3d 1143 [4th Cir. 8/23/2000], 2000 US App. LEXIS 21236), the US Court of Appeals for the Fourth Circuit ruled that a local school board had violated the ADA when its emergency plan failed to provide for the safe evacuation of a disabled student during a bomb threat that triggered the evacuation of the other students.¹⁸ This decision implies that emergency planners must make special efforts to ensure that persons with disabilities have the materials they need to effectively shelter in place when governments plan for the general population to do so.

SHELTERING IN PLACE AS AN EMERGENCY PROTECTIVE ACTION

Protection from exposure to hazardous vapors can be accomplished in two ways: leaving the area (evacuation) before the vapor plume arrives or taking shelter. Evacuation has the advantage in that protection from exposure is complete. In areas from which it is not possible to relocate before the plume arrives, sheltering in a building with little infiltration of outside air offers the best protection available. However, the degree of protection offered by sheltering is affected by how long shelters are exposed to the agent, the methods used to reduce air infiltration, and whether sheltering is started (i.e., a room is sealed) before arrival of the plume. In practice and theory, up to four levels of sheltering effectiveness can be implemented:

- **Normal:** Involves closing and locking all windows and doors, closing dampers and vents, turning off fans and heating and air-conditioning systems, and remaining in an interior safe room.
- **Expedient:** Involves fast and simple additions to normal sheltering and may include placing a rolled towel at the base of the safe room door; taping over air vents, electrical outlets, or other openings in the safe room; and taping plastic sheets over windows and doors.
- **Enhanced:** Involves preparatory measures such as caulking, sealing, and structural modifications that reduce the ability of vapors to enter a building or safe room in addition to normal or expedient sheltering actions.
- **Pressurized:** Involves using special filter-blower units to pressurize a tightly sealed safe room. A filter-blower filters incoming air and keeps out contaminated air by producing an outflow of air through building leakage points.

Scientific studies have found that airflow into a windowed bathroom used as a shelter room can be reduced to a mean of 16.5 percent by simply placing a rolled towel at the base of the door and taping over any vents. By going the next step, putting tape around the door and taping a sheet of plastic over the window, airflow can be reduced by a mean of 34.3 percent.¹⁹ Oak Ridge National Laboratory found that taping was essential to reducing air infiltration, while plastic sheeting was not a critical element for reducing air infiltration.²⁰ Using a recirculating charcoal filter fan in the room may provide even more protection.²¹ A disadvantage of sheltering in place is that the protection it offers decreases over the time that the shelter is exposed to an agent. However, studies have found that even normal sheltering can be protective for relatively long periods of time (even for as much as five hours) following a one-hour exposure to a dosage.²¹

Persons and/or households need time to implement both normal and expedient sheltering. While normal sheltering has been estimated to take five to 10 minutes once the decision to shelter is made by a household, expedient shelter preparations have been found to take longer. Data from a limited set of trials by individuals who had been provided with duct tape, plastic, written instructions, and checklists revealed that it was likely to take an average of 17 minutes, with a minimum of three minutes and a maximum of 39 minutes.²² No data exist on the time needed to perform expedient sheltering by persons with physical, mental, or medical impairments, although it is recognized that the ability to create expedient sheltering by taping and sealing is affected by variables such as age, mobility, and physical impairment.²⁰

One example of how expedient shelter-in-place techniques are being applied in the United States is provided by the Chemical Stockpile Emergency Preparedness (CSEP) program. The CSEP program is a federally funded effort to improve emergency preparedness in communities that closely surround the eight unitary chemical weapons storage installations in the continental United States. Although all of the obsolete and deteriorating nerve and blister agents contained in these US Army facilities is scheduled to be destroyed under the terms of both federal statute and the multilateral Chemical Weapons Convention, extensive plans have been developed to mitigate the consequences in the unlikely event of an accident before the destruction is completed.

Shelter-in-place (SIP) kits are being offered to the general population in various CSEP program communities to promote expedient sheltering. Although SIP kits vary among communities, each kit generally consists of a roll of duct tape, clear plastic sheeting, scissors, installation instructions, and a mix of other things (e.g., flashlight, towel, AM/FM radio, batteries, glow stick, and instructional video). The purpose of the kit is to provide each resident with the materials necessary to seal a room and reduce infiltration of contaminated air from the accidental release of chemical weapons agents.

SIP kit users have to be capable of cutting the plastic sheeting into properly sized covers for windows,

Table 1. Calculated air exchange results

Test	Start/ End	SF ₆ Conc. (ppb)	Time (h)	ACH	Temp. (°F)	Wind direction	Wind speed (m/s)	Wind Speed (mph)	Test conditions
1	Start	7,641	1.27	0.128	77	NEE	3.4	7.6	Normal shelter in place: Exterior and interior doors closed, no sealing
	End	6,496							
2	Start	5,446	1.38	0.088	79	NEE	3.0	6.7	Baseline: Towel at interior door, vents and exterior door sealed
	End	4,819							
3	Start	3,931	1.65	0.045	79	E	3.0	6.7	Self-adhering laminate strips: Seal interior door and windows
	End	3,649							
4	Start	2,142	1.67	0.038	82	WSW	3.8	8.5	Self-adhering laminate sheet: Cover interior door and windows
	End	2,011							
5	Start	23,248	1.17	0.074	86	W	3.6	8.1	Baseline: Towel at interior door, vents and exterior door sealed
	End	21,318							
6.1	Start	18,986	0.95	0.023	87	W	3.6	8.1	Painter's tape: Seal interior door and windows (prestorm test data)
	End	18,568							
6.2	Start	18,529	0.50	0.126	73	N	5.4	12.1	Painter's tape: Seal interior door and windows (storm test data)
	End	17,397							
7	Start	15,565	1.20	0.031	65	E	2.0	4.5	Painter's tape: Seal interior door and windows (poststorm test data)
	End	15,004							
8	Start	4,417	0.95	0.130	67	NNE	4.5	10.1	Baseline: Towel at interior door, vents and exterior door sealed
	End	3,902							
9	Start	3,091	1.50	0.141	66	NNE	5.9	13.2	Shelter kit: Plastic sheets and duct tape used to seal interior door and windows
	End	2,500							
10	Start	2,060	0.33	0.216	65	NNE	5.6	12.5	Baseline: Towel at interior doors, vents and exterior door sealed (breezy conditions)
	End	1,917							
11	Start	20,012	1.27	0.158	64	NNE	5.0	11.2	Weather strip: Applied to interior door and windows
	End	16,375							
12	Start	14,811	1.50	0.061	69	NEE	3.2	7.2	Adhesive film: Applied to interior doors and windows
	End	13,515							
13	Start	11,766	1.17	0.064	70	NEE	3.2	7.2	Baseline: Towel at interior door, vents and exterior door sealed
	End	10,922							

vents, and doors in the selected shelter room; cutting duct-tape strips to attach the covers; and taping over as many remaining openings (e.g., space around pipes and electrical outlets) as possible.

ALTERNATIVE SHELTER-IN-PLACE MATERIALS FOR PERSONS WITH SPECIAL NEEDS

One of the CSEP program communities surrounds the Anniston Army Depot in Anniston, Alabama. Originally the storage site for 2,253 tons of chemical weapons agents and munitions, more than 350,000 people now live within the six-county planning zone where emergency plans have been prepared. Destruction of this stockpile began in August 2003.

The Alabama Emergency Management Agency (AEMA) is responsible for emergency preparedness in case of a chemical weapons accident at the depot, including the area's special-needs population. As part of a CSEP program-funded effort, AEMA sponsored a study to identify and plan for persons with physical, medical, or mental problems; transportation dependence; or children who are sometimes home alone (latch-key kids) and would be unable to protect themselves and have no nearby family, neighbors, or friends to assist in time.¹⁸ By mid-2003, approximately 6,000 persons had registered as needing assistance should an emergency requiring evacuation or sheltering in place arise.

In 2002, AEMA requested that ANL conduct a series of preliminary engineering tests in a real-world setting to identify easier-to-use sealing materials for sheltering in place by persons with special needs under stressful conditions. The alternative materials needed to be commercially available and acceptable to persons with special needs. They would serve either as an alternative or supplement to the standard SIP kit containing duct tape and plastic.

Based on historical field studies, emergency threats to residents from toxic releases were found to require the quick creation of an effective safe room under varying conditions with a minimum of tools or steps and an easy return to normal without hardship or disrepair to mitigate a postresponse trauma. Thus, materials under consideration were evaluated with regard to three criteria:

- effectiveness in reducing air infiltration into a shelter room;
- ease of application; and
- ease of removal.

It was also required that sheltering materials not hinder the exit of room occupants after the shelter period ended.

The research did not include a comprehensive comparison of sealing effectiveness of the duct tape/plastic combination relative to alternative SIP materials. The duct tape/plastic combination has been extensively tested, widely used by the public in a variety of settings, and the subject of considerable education and outreach efforts over the years by numerous emergency planning and response organizations. Our study was specifically intended to identify alternatives for those who cannot readily make use of the traditional materials. Because of the potential impact on public health and safety, it would be imprudent to conclude that any alternatives to duct tape and plastic are superior for general usage without additional research.

METHODS

Sheltering materials tested

In June 2003, ANL researchers conducted air-exchange (infiltration) tests to compare the sealing effectiveness of a SIP kit being offered through the CSEP Program to Calhoun County, Alabama, residents relative to four alternative materials. The tests were conducted in a one-story, two-bedroom brick cottage with double-glazed windows located on ANL property (Cottage 615). The SIP kit contained:

- one roll of duct tape (silver 2"-wide Tyco Adhesives Nashua® 300 polyethylene-coated 10-mil cloth tape with rubber adhesive);
- one 10 × 25 ft. sheet of clear plastic (TRM Manufacturing No. 12231 6-mil);

- one pair of blunt-edge, stainless-steel autoclavable scissors with printed instructions entitled *Scissors Safety*;
- one 40 × 21 in. white 100-percent cotton towel (RN 54455-J02);
- one shelter-in-place instructional VHS videotape; and
- one two-pocket cardboard folder containing two documents entitled *Outfit Your Shelter-in-Place Kit* and *Shelter-in-Place Instructions*.

The commercially available alternative materials were:

- painter's tape (3M 2 in. wide blue Scotch Safe-Release® Painters' Masking Tape No. 2090);
- self-adhering laminate (Con-Tact® ONYZ 9918);
- foam weather strip (high-density gray foam tape, 1/4 × 1/2-in. wide, No. 02279); and
- plastic film and adhesive (M-D Building Products' Shrink & Seal® Window Kit No. 04200).

Test location characteristics

The cottage in which the materials were tested had an air exchange rate of between 0.02 and 0.22 air changes per hour (ACH) during testing, which is a relatively low baseline rate. Air infiltration rates are affected by type of construction, wind conditions, and indoor/outdoor temperature differences. Air infiltration rates in homes constructed before 1975 generally range between 0.2 and 3.0 ACH. In contrast, air infiltration in homes constructed after the energy crisis of the 1970s with increased tightness and attention to conservation is much lower, ranging between

less than 0.1 to about 0.75 ACH overall. Higher ACH occur in homes when adverse weather conditions prevail. Efforts to block air infiltration with various materials have more effect in buildings that are "leaky"; i.e., those with relatively high air infiltration rates.

The tests were conducted in a simulated shelter space—a master bedroom (156 sq. ft.) with an adjoining bathroom (40 sq. ft.) located at the northeast corner of the cottage. During baseline and material testing, the one exterior door, one floor vent, and two ceiling vents remained sealed with self-adhering laminate. Test materials were applied to the three windows in the shelter space and to an interior connecting door that led to a hallway.

Air exchange rates in the cottage were correlated with wind speed and direction. In addition, carbon dioxide accumulation, indoor temperature, and relative humidity were monitored. During the four-day test period, the indoor temperature varied between 63°F and 76°F, indoor/outdoor temperature differences ranged between 0°F and 15°F, and relative humidity varied between 56 percent and 88 percent. The stack effect²³ (temperature differences between indoors and outdoors cause density differences and, therefore, pressure differences that drive infiltration) was practically nonexistent because of the narrow indoor/outdoor temperature range, so wind speed and direction were the only weather-related factors influencing ACH.

Air exchange test methodology

ANL selected an air infiltration test method that has been widely used in determining air exchanges. A diluted tracer gas, sulfur hexafluoride (SF₆), was injected into the shelter space from a Tedlar gas bag (which was promptly removed) and dispersed with a circulating fan for each of 13 test conditions. SF₆ has been the most widely used tracer gas for measuring air infiltration for over 32 years because it is nontoxic, can be measured in low concentrations (parts per billion, or ppb), and it is not normally present in the environment. SF₆ concentrations ranged from about 2,000 to 25,000 ppb. No fresh SF₆ was injected into the shelter room until the concentration dropped

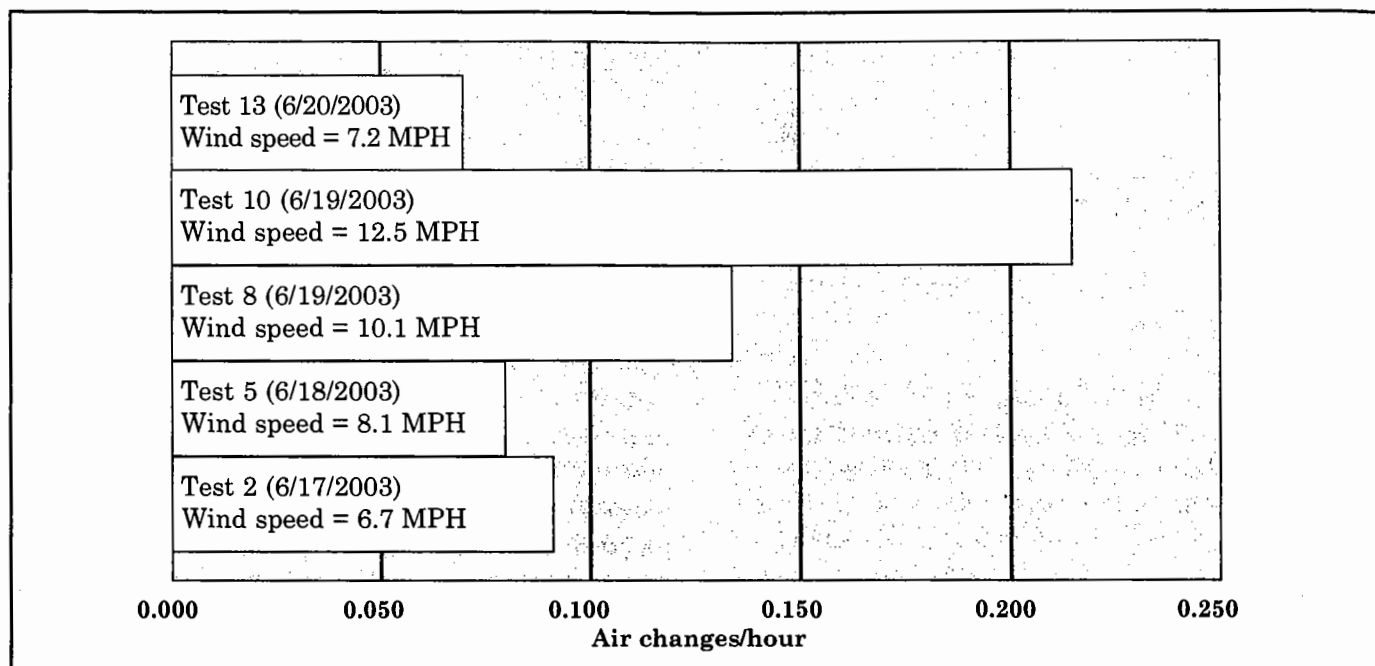


Figure 2. Baseline air exchange measurements in Cottage 615.

below about 2,000 to 4,000 ppb. For that reason, the concentration of SF_6 at the start of a given test could be anywhere from 2,000 to 25,000 ppb. The starting concentration does not affect the accuracy of the measurement, because the air exchange rate is a function of the ratios of concentrations at the start and finish of each test.

A MIRAN SaphIRE® Analyzer (Thermo Environmental Instruments, Inc., Foxboro, MA) continuously measured the steady tracer gas decay between the starting and ending concentrations (2,000 to 25,000 ppb). The electronic data log of air concentration changes at relatively constant wind speeds was used to calculate ACH when the SIP kit and each of the four alternate materials were used under a variety of conditions. The relationship between concentration and time in a well-mixed ventilated space is:

$$\text{Air exchange rate} = \ln (C1/C2)/(T2 - T1)$$

where \ln = natural logarithm; C1 and C2 = concentration at start and end of test, respectively; and T2 and T1 = time in hours at the end and start of the test, respectively.

To strengthen the validity of the analysis, five repeats of the baseline conditions (no sealant applied) were made to account for changes in weather conditions. These tests provided a baseline for comparing sealing methods under similar weather conditions. Local weather data were collected from an onsite ANL automated weather data system.

AIR EXCHANGE TEST FINDINGS

Data collected during each test were transferred to a spreadsheet and plotted against time. The plots were used to determine when the gas was sufficiently well mixed to yield a smooth concentration decay curve that would be truly representative of the natural air exchange rate being measured. Calculated air exchange results and the concurrent temperature and wind speed and direction for the 13 tests are shown in Table 1. The results compared to applicable baseline conditions are shown in Figures 2, 3, and 4.

Results show that painter's tape and self-adhering laminate were most effective in reducing the air exchange rates in the simulated expedient shelter. For example, at a 3.6 meters per second (m/s) wind speed (8.1 mph), the average air exchange rate with the painter's tape was 0.023 ACH (Test 6.1); at 3.0

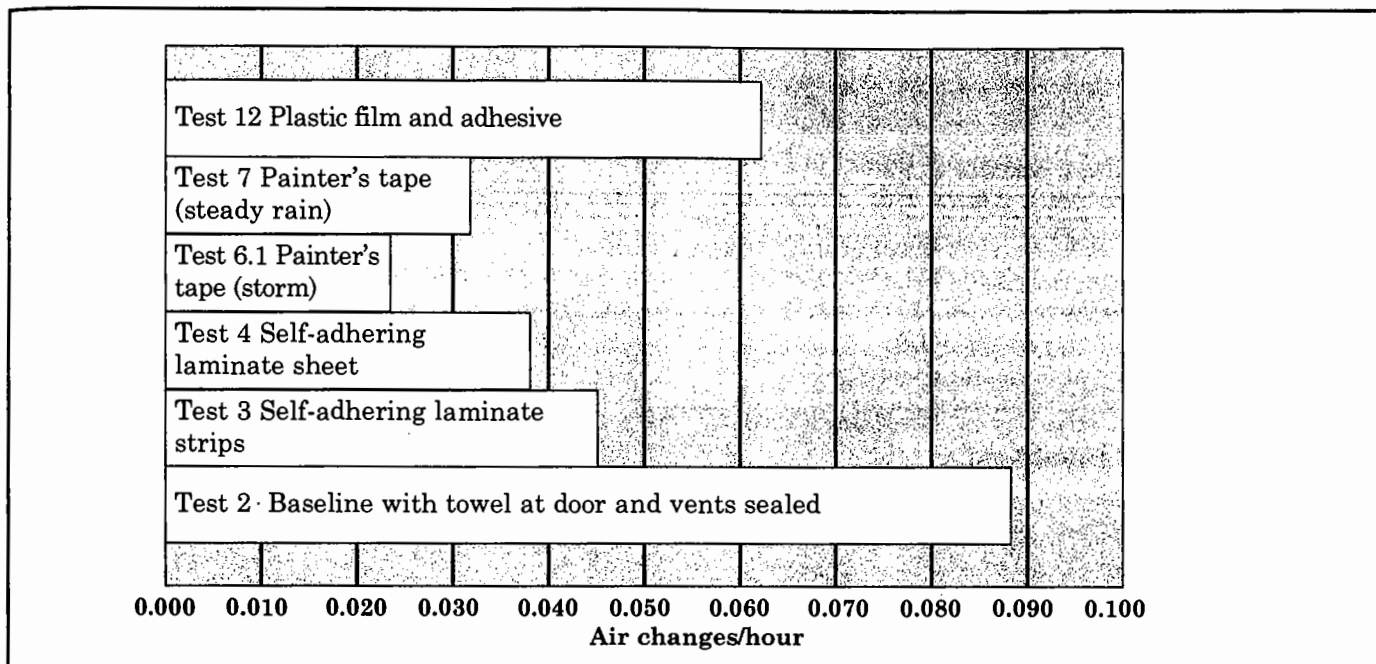


Figure 3. Air exchange measurements at sealed room in Cottage 615 with wind speed at 3 m/s (6.7 mph).

m/s (6.7 mph), the average air exchange rate with the self-adhering laminate was about 0.045 ACH (Test 3). The baseline air exchange rate at a wind speed of about 3.0 m/s (6.7 mph) was 0.088 ACH.

Wind speed and direction play especially important roles in determining air exchange rates in expedient shelters. The shelter during these tests had a northeast face with a double window and a northwest face with single windows in the bedroom and bathroom. The wind was most effective in increasing the air exchange rate in the shelter room when it blew directly from the north, thereby impacting both walls at an angle and creating maximum windward pressure at the given wind speed. During the painter's tape test (Test 6), the average wind speed increased from 3.6 m/s (8.1 mph) to 5.4 m/s (12.1 mph) and the direction switched to directly from the north. The air exchange rate increased from 0.023 to 0.126 ACH. The wind direction shifted a bit but stayed at approximately 5-6 m/s (11.2-13.4 mph) during the subsequent baseline test, and the baseline air exchange rate was measured at 0.216 ACH. These results reinforce the view that the painter's tape was substantially effective in reducing the air exchange rate in the shelter, especially at higher wind speeds. A baseline air exchange rate of 0.216 ACH at a wind speed of

5.6 m/s (12.5 mph) indicates relatively tight construction; therefore, it is our opinion that providing an effective sealant becomes even more important for expedient shelters that are less tight.

SUMMARY OF AIR EXCHANGE FINDINGS

All of the results showed a reduction in the air exchange rates relative to the baseline data. The tests showed that applying the sealant directly over air gaps (cracks, crevices, and seams through which air infiltration occurs) around windows and the interior door was more effective in reducing air infiltration than covering the windows and the interior door with a plastic sheet that is taped (or attached) to the surfaces outside the air gaps. In the former case, wind pressure affects only the outside surface of the sealant adjoining the air gaps, and the force on the sealant is miniscule. However, in the latter case, wind pressure is transmitted through the air gaps and is then applied to the entire outside surface of the plastic sheet, which makes the force on the sealant vastly greater.

Weather, especially wind speed and direction, is the major driver of air exchange rates in any given home. The tests were conducted under moderate

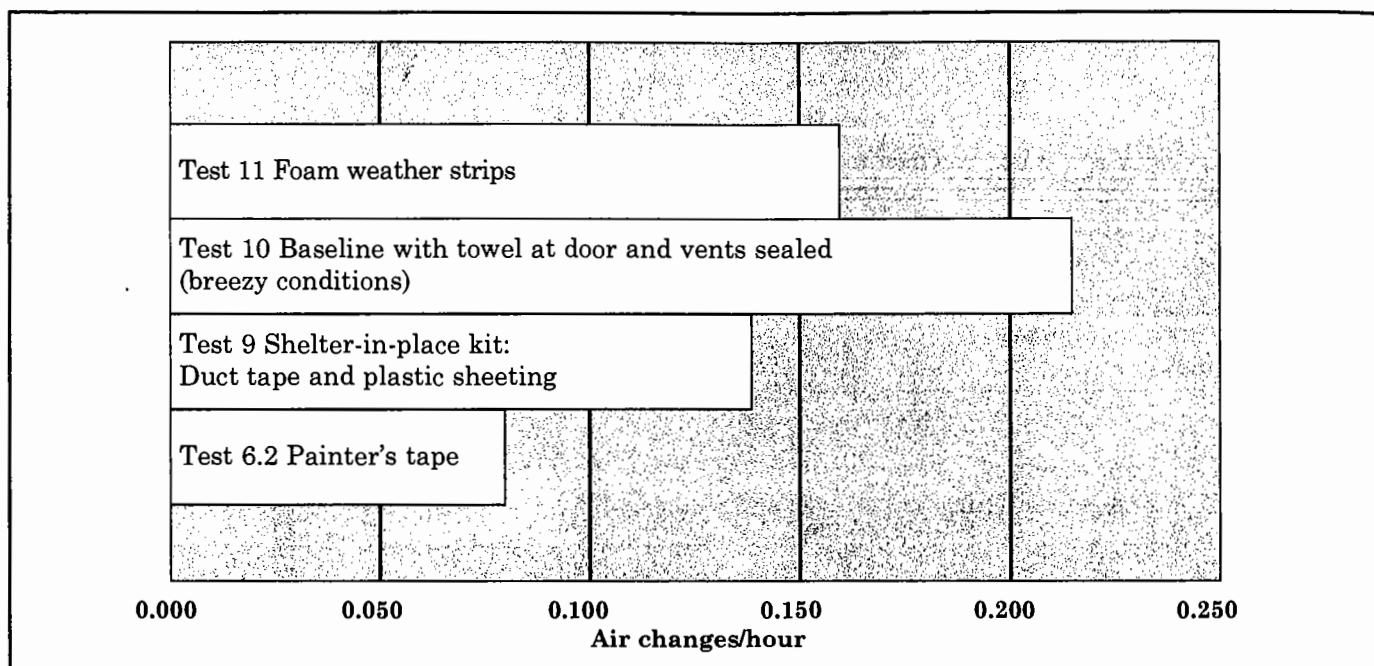


Figure 4. Air exchange measurements at sealed room in Cottage 615 with wind speed at 5 m/s (11.2 mph).

summertime conditions with fairly low wind speeds and a mild outdoor temperature, resulting in relatively low air exchange rates. Greater wind speeds substantially increase air infiltration, indicating the need to effectively seal leaky structures.

Carbon dioxide (CO₂) measurements were also made during the tests to assess the buildup of CO₂ in the sealed room with one occupant present. CO₂ was measured with a Q-TRAK™ IAQ Monitor Model 8550 (TSI Inc., St. Paul, MN) using a nondispersive infrared sensor in a range of 0-5,000 ppm with a resolution of 1 ppm. Measurement of CO₂ accumulation in the shelter area during the material tests did not demonstrate a tendency for unsafe conditions to occur. Calculations indicate that even extremely low air exchange rates would be unlikely to produce unsafe conditions, even if the sheltering period were to last for eight hours.

RANKING OF SHELTERING MATERIALS

The following materials were ranked for their effectiveness in reducing air infiltration under equivalent conditions:

1. painter's tape

2. self-adhering laminate

3. SIP kit

4. plastic film and adhesive

5. foam weather strip

The painter's tape and the self-adhering laminate were at least as effective in reducing air infiltration as the plastic sheeting and duct tape that were tested. Weather stripping and the film-and-adhesive options were least effective.

A subjective ease-of-use ranking was also developed by the research team (i.e., those who applied the materials to the shelter room doors, windows, and vents and then removed them after the test sessions). In this ranking, the self-adhering laminate and the painter's tape were found to be about equally easy to apply. The application process involved only one piece of material, allowed plenty of margin for error due to the ability to easily realign the material, and required a minimum of tools, as the laminate can be easily cut using a variety of implements, while the painter's tape can be easily cut or torn by hand.

Meanwhile, the duct-tape-and-plastic and the foam weather strip were equally difficult to apply. The application process for duct tape and plastic involved cutting covers for doors and windows from a large sheet of plastic and taping them to walls using duct-tape strips. Handling and cutting duct tape can be difficult due to its high tensile strength and thickness and because the strength of the adhesive makes the realignment of covers problematic, especially when the tape becomes crimped. Its removal also caused damage to paint, wallpaper, and drywall. Foam weather strip required careful placement around doorjamb and window frames, especially where strips met at corners, and either scissors or a cutting tool was used to trim the strips to proper lengths.

Hands-on tests of application by elderly and special-needs residents in Oxford and Hobson City, Alabama, were also conducted by researchers from HGS Engineering, Inc., at two senior citizen centers on June 3-4, 2003. Three alternative products (self-adhering laminate, painter's tape, and foam weather strip) were demonstrated, and the test volunteers were given the opportunity to practice their application on a mock window provided for that purpose. Overwhelmingly, those present chose the self-adhering laminate as the product best suited for their needs, with a few selecting painter's tape. However, participants suggested that all three products be provided in a modified SIP kit for persons with special needs, leaving the final choice of which to apply to each individual based on his or her circumstances.²⁴

CONCLUSIONS AND RECOMMENDATIONS

Various sealing methods were found to be effective in reducing the air exchange rate in the test room. With looser (leakier) construction, higher wind speeds, and/or colder temperatures, the effectiveness of sealants is expected to increase. The CO₂ accumulation that would be caused by one to four people being confined in a small sealed room for eight hours or less is unlikely to produce a life-threatening shortage of oxygen.

As a strategy for preventing infiltration, it is better to apply sealants directly over air gaps rather than to bridge the air gaps with plastic sheeting

anchored with tape or adhesive. The use of plastic sheeting allows transmission of air pressure through the air gaps, which causes billowing and possible in-leakage due to mechanical action.

The painter's tape and self-adhering laminate tested in this study were effective and practical sealants and required a minimum of dexterity. The self-adhering laminate can be applied over an entire window and has the advantage that it can be pressed against any damaged window panes. It can also be applied over door frames, including extruding door hinges and knobs. In addition, self-adhering laminate can be cut into strips and used to seal crevices, outlets, and vents. Painter's tape can be cut or torn to size to similarly cover all air gaps. Both painter's tape and self-adhering laminate should be seriously considered for persons with special needs in lieu of the duct-tape-and-plastic combination, which is less effective and less practical to use and remove. Furthermore, duct tape can cause damage to walls and other finished surfaces during removal. Foam weather strip and the film-and-adhesive method were least effective in reducing air infiltration.

Painter's tape and self-adhering laminate should be made available for use by persons with special needs to expediently shelter in place when government officials request the general population to do so. This single study does not justify, and should not be interpreted as recommending, substitution or replacement of duct tape and plastic with painter's tape, self-adhering laminate, or any of the other materials tested during this project in households where residents are capable of handling the traditional materials appropriately. Additional research would be a prerequisite to making such a recommendation.

Sheltering in place is an increasingly important protective action against technological hazards and terrorist threats. This project strongly suggests that a comprehensive study of alternative materials that may be used to expediently shelter in place in residential structures is needed. No studies were identified that rigorously compare the effectiveness of different types of duct tape and plastic to that of other easily available materials, such as painter's tape or self-adhering laminate. A research program to assess the effectiveness, application ease, and

removal ease of a variety of products in a range of structures across varying environmental conditions and against different vapor challenges might help identify alternative materials with even greater efficacy for use by the general population.

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